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OPTICAL, MAGNETIC, AND ELECTRICAL PROPERTIES OF TEKTITES, METEORITES, AND OTHER SPACE RELATED MATERIALS

submitted by

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INTRODUCTION

In 1965 the National Aeronautics and Space Administration initiated support to Howard University for the study of the optical, and magnetic properties of Tektites and other space related materials. The contract was terminated in 1974. The following report summarizes the most important results of this research effort. Dr. John O'Keefe has been the project monitor since the inception of the project, and we would like to thank him for his continued interest, helpful suggestions, and encouragement during the course of the project. We are also grateful to the National Aeronautics and Space Agency for this support.

The original scope of the project was to study the infrared absorption of water and the magnetic properties of the iron in tektites. Subsequently the work was expanded to include other properties of tektites and lunar materials.

Infrared Studies:

The water contents of some tektites, impactites, and artificial glass of tektite composition were determined by infrared analysis. Calibration was based on a series of rhyolitic obsidian glasses previously analyzed by I. Friedman by a manometric technique. With one exception, the twenty-five tektites measured had an average water content of 0.012 ± 0.004 wt%. Water analyses of a series of glasses made in a solar furnace at atmospheric pressure, synthetic tektite glasses, and impactites showed an average water content of $0.043 \pm 0.013\%$ and hence suggest that they were formed in an atmosphere having a higher water content than that in which tektites were formed. A comparison of the water content of selected small areas in tektite thin sections showed a nonuniform distribution and somewhat lower water content along what appears to be the aerodynamically heated side of the tektite. The results generally suggested that tektites were not formed under normal atmospheric pressure but in a partial-to-high vacuum. This work was published in Journal of Geophysical Research, Vol. 74, pages 1475-1483, 1969, [copy enclosed].

Iron in Tektites:

Previous magnetic measurements of tektites indicated the possible presence of finely divided metallic iron or iron oxide particles in essentially all tektites. In order to determine the state of the iron particles, low angle X-ray scattering measurements were made. However, the results were marginal and this technique was abandoned in favor of Mossbauer Measurements. The Mossbauer measurements showed the presence of ferrous iron, but no ferric iron in agreement with our previous magnetic sutdies. Further, it was shown that the isomer shift and quadropole splitting was different for each strewn field. This fact seemed to indicate that the conditions of formation of each tektite member in a given strewn field must be remarkably similar, but different from any other strewn field. Further, the total absorption appeared to be a linear function of the ferrous iron content, and the slope of the curve is characteristic of the strewn field. Details of this work are presented in the January 1967 semiannual status report to NASA.

Magnetic Properties of Microtektites:

The magnetic susceptibility, magnetization, and Curie constants were measured for 17 normal and 11 bottle-green microtektites found in deep-sea sediment cores. Unlike tektites, all the normal microtektite specimens had a significant intensity of magnetization. This was ascribed to a ferromagnetic iron oxide film on the surface of the microtektites which could be removed by acid leaching. The bulk iron within the glass was assumed to be primarily in the ferrous state, as it is in tektites, and the ferrour iron content was calculated from the Curie constant and compared with the total iron determined with the electron probe. Within experimental errors there was a one-to-one correspondence between the calculated ferrous iron and the measured total iron, showing a strong similarity to tektite glass. The bottle-green microtektites showed properties similar to the normal variety before leaching. Although the leaching process did not affect the bulk iron content of the normal microtektite glass, it was possible to remove all iron from the bottle-green glass. In this respect the bottle-green microtektites are quite different from normal microtektites or tektites. The solubility suggests that the bottle-green specimens may have partially reacted with the sea water, thus altering their original magnetic properties. This work was published in the Journal of Geophysical Research, Vol. 74, pages 6825-6833, 1969 [copy enclosed].

Magnetic Studies of Lunar Materials:

When the lunar samples became available the emphasis of the research was shifted from tektites to lunar samples. Because of our previous experience with tektite glass the initial magnetic studies were focused on individual glass spherules from the lunar fines of the Apollo 11 mission.

The magnetic properties of eight glass spherules (0·02–1·5 mg) from the Apollo 11 bulk lunar fines were investigated first. All of the specimens showed strong paramagnetism due to Fe^{2+}, and most of the specimens also showed soft and hard ferromagnetic components. The iron in the form of spheres is the source of the hard magnetic component and the amount present was calculated from the high field saturation magnetization, and from the temperature-independent susceptibility at low and high temperatures. Essentially, the same amount of iron (about 0.5 per cent) could be determined by all three methods confirming that the hard component is due to nickel-iron or iron-spheres in the glass. The soft component is due to odd-shaped fragmental iron or ferromagnetic minerals. No significant superparamagnetism was observed. This work was published in Proc. Apollo 11 Lunar Sci. Conf., Geochem. Cosmochim. Acta., Suppl. 1, Vol. 3, pages 2453–2467 [copy enclosed].

With the return of Apollo 12, these measurements were extended to include samples of individual glass spherules from Apollo 12, and the temperature range of the measurements was expanded to include liquid helium temperatures. The magnetic properties of eight glass spherules (0.03–0.24 mg) from the Apollo 12 lunar fines, one fragment (44 mg) from glass spatter collected during the Apollo 12 mission, and eleven glass spherules from the apollo 11 fines were determined. As in the case of the Apollo 11 specimens, previously studied, the specimens showed a strong paramagnetism, and an easily and difficultly magnetized ferromagnetic component. An intermediate ferromagnetic component was found which was small and contributed little to the total susceptibility. Subsequent remeasurements of the spherules from both the Apollo 11 and Apollo 12 samples showed gradual changes in the magnetic properties with time in many of the specimens. Selected specimens were heat treated in controlled atmospheres to determine the effect of oxidation which was found to be primarily a surface effect. The metallic iron varied from about 0.01 to 1% and the total iron calculated from the magnetic measurements compared well with electron probe analysis. The data indicated that the titanium is essentially all in the Ti^{4+} state.

Several specimens were also studied at temperatures as low as 4.2 K in order to determine if the Curie-Weiss law held at low temperatures. The data follow a Curie-Weiss law with a Weiss temperature of about 3 K. Comparison was also made with tektites which in general had Weiss temperatures about one-half of the value found for the lunar specimens. A final paper describing the work was published in the Proc. Second Lunar Sci. Conf., Geochim. Cosmochim. Acta, Suppl. 2., Vol. 3, pages 2433-2449, 1971 [copy enclosed].

In the next phase of the work the magnetic susceptibility of 11 glass spherules from the Apollo 14 lunar fines were measured from room temperature to 4 K. Data taken at room temperature, 77 K, and 4.2 K, showed that the soft saturation magnetization was temperature independent. In the temperature range 300 to 77 K the temperaturedependent component of the magnetic susceptibility obeyed the Curie law. Susceptibility measurements on these same specimens and in addition 14 similar spherules from the Apollo 11 and 12 mission showed a Curie-Weiss relation at temperatures less than 77 K with a Weiss temperature of 3-7 degrees in contrast to 2-3 degrees found for tektites and synthetic glasses of tektite composition. A proposed model and a theoretical expression closely predict the variation of the susceptibility of the glass spherules with temperature. The model infers the Weiss temperature is associated not only with the antiferromagnetic mineral inclusions within the glass but also with a distortion of the octrahedral ligand field of the Fe^{2+} ions in the glass phase.

The data showed that in the glass spherules of the Apollo 14 fines the concentration of antiferromagnetic inclusions is greater and the ligand field distortion is less than for similar specimens in the Apollo 11 and Apollo 12 fines. The concentration of Fe^{2+} in the glassy phase is essentially constant from spherule to spherule in a given sample of lunar fines and there is evidence that the particulate minerals in the glass suffered little or no dissolution after injection into the glass. The later conclusions are a strong indication that the glass phase is saturated with respect to iron and that some or all of the metallic iron spherules were formed by reduction. The saturation iron concentration on the glassy phase of the Apollo 14 spherules is less than in the Apollo 11 and 12 specimens indicating a lower temperature of formation for the Apollo 14 specimens. This work was reported in preliminary form in Lunar Science III, pages 752-753, 1972, and a final paper in the Proceedings of the Third Lunar Science Conference, Supplement 3, Geochim. Cosmochim. Acta, Vol. 3, pages 2465-2478, 1972 [copies enclosed].

A few very small glass spherules were obtained from the Lunar 20 mission for further study. Magnetic susceptibility measurements were made on four glass spherules and fragments; two at 300 K and two from 300 K to 4 K. From these data the magnetic susceptibility extrapolated to infinite field, the magnetization at low fields and also the saturation magnetizaiton at high fields, the Curie constant, the Weiss temperature, and the temperature-independent susceptibility were determined. Using a model previously proposed for the Apollo specimens, the Curie constant of the antiferromagnetic inclusions and a zero field splitting parameter were calculated for the same specimens. The data show the relatively low concentration of iron in all forms in these specimens. In addition, the Weiss temperature is lower than that measured for the Apollo specimens, and can be attributed almost entirely to the ligand field distortion about the Fe^{2+} ions in the glassy phase. The data further suggest that the Lunar 20 specimens cooled more slowly than those of the Apollo missions, and that some of the antiferromagnetic inclusions in the glass may have crystallized from the glass during cooling. These results were published in Geochim. Cosmochim.Acta, Vol. 37, pages 1053-1062, 1973 [copy enclosed].

In the final phase of the program our attention was focused on the superparamagnetism and antiferromagnetic properties of the lunar glass. The fines show substantial superparamagnetism but the individual glass spherules removed from the fines exhibit little or no superparamagnetism. On the other hand, the antiferromagnetism of the lunar glass is relatively large. The magnetic susceptibility of 11 glass spherules from the Apollo 15, 16, and 17 fines and two specimens of a relatively large glass spherical shell were studied as a function of temperature from room remperature to liquid helium temperatures. All but one specimen showed the presence of antiferromagnetic inclusions. Closely spaced temperature measurements of the magnetic susceptibility below 77 K on five of the specimens showed antiferromagnetic temperature transitions (Neel transitions). With the exception of ilmenite in one specimen, these transitions did not correspond to any transitions in known antiferromagnetic compounds. The preliminary details of these measurements are reported in Lunar Science IV, pages 728-731, 1973, and Lunar Science V, pages 698-699, 1974. The first report on the antiferromagnetic transitions was published in Earth and Planetary Science Letters, 21, pages 85-90, 1973 and a paper describing our work on the superparamagnetism in lunar glass is in preparation.